Improving the bulk formula for sea-surface fluxes

Final report

Larry Mahrt
College of Oceanic and Atmospheric Sciences
Oregon State University
Corvallis, OR 97331
phone: (541) 737-5211   fax: (541) 737-2540
email: mahrt@coas.oregonstate.edu
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LONG-TERM GOAL

Derive a more flexibile form of the bulk forumula for sea-surface fluxes that does not require compliance with Monin-Obukhov similarity theory nor definition of the surface roughness length.

OBJECTIVES

The most important objectives are to generalize the bulk formula to: a) better approximate fluxes for stable weak-wind cases to accommodate the influence of unresolved mesoscale motions, b) account for reduced efficiency of moisture fluxes over cooler water, c) allow for confused seas and weak winds dominated by mesoscale motions through probability distributions of transfer coefficients and d) rexamine the bulk for formula for strong wind conditions.

APPROACH

The bulk formula will be generalized by analyzing several LoneEZ and recent CIRPAS Twin Otter aircraft data sets. Data from the CIRPAS Twin Otter April 08 Pilot Experiment is emphasized in the initial analyses with additional data being added. This analysis is supported by a new QC and analysis package contructed during the first year of the grant.

WORK COMPLETED

During the past year, work was completed on formulation of the roughness length for moisture and a short paper was submitted and accepted in QJRMS. During the past year, several additional aircraft data sets were added including GOTEX and CARMA IV (Monterey). After QC'ing the data, preliminary analysis was initiated. These data scts have been combined with previous data sets for reconsideration of the bulk formula. At the end of this grant, I found some difficulties with the NCAR C130 aircraft wind fields and I am currently working with NCAR on this problem.

RESULTS

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REPORT DOCUMENTATION PAGE

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

We found that the roughness lengths for momentum and sensible heat for mid- and high latitudes appear to be smaller than those given by widely used open-ocean models in conditions of weak to moderate winds. The reduction in roughness length, compared to the open-ocean model, is largest for moisture transport. The less efficient transfer of moisture compared to heat for these datasets is apparently related to the dynamic nature of temperature and the fact that temperature fluctuations dominate buoyancy generation of turbulence. We also identified the potential importance of small variations of the SST for small mean air-sea temperature difference, as occurs for most of the open ocean.

15. SUBJECT TERMS

bulk formula, drag coefficient, mesoscale variability, surface fluxes

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The roughness lengths for momentum and sensible heat appear to be smaller than those given by widely used open-ocean models (TOGA COARE algorithm) in conditions of weak to moderate winds. The reduction in roughness length, compared to the open-ocean model, is largest for moisture transport. The less efficient transfer of moisture, compared to heat, for these datasets is apparently related to the dynamic nature of temperature and the fact that temperature fluctuations dominate buoyancy generation of turbulence, which was not observed in the western tropical Pacific warm pool data used to develop the original COARE algorithm. Unlike the usual formula, these data suggest that the scalar roughness length ratio (z_{oh} divided by z_{oq}) is larger than unity for weak to moderate winds (see Figure 1). The reduced latent heat flux is supported by five different data sets from the coastal zone, including measurements from aircraft, a tower and a ship. Latent heat fluxes were found to be 25 to 50% smaller than predicted by the COARE algorithm, depending on the dataset. The generality of these results, in particular their application to the open ocean or to situations where wave state effects are important, is not yet known.
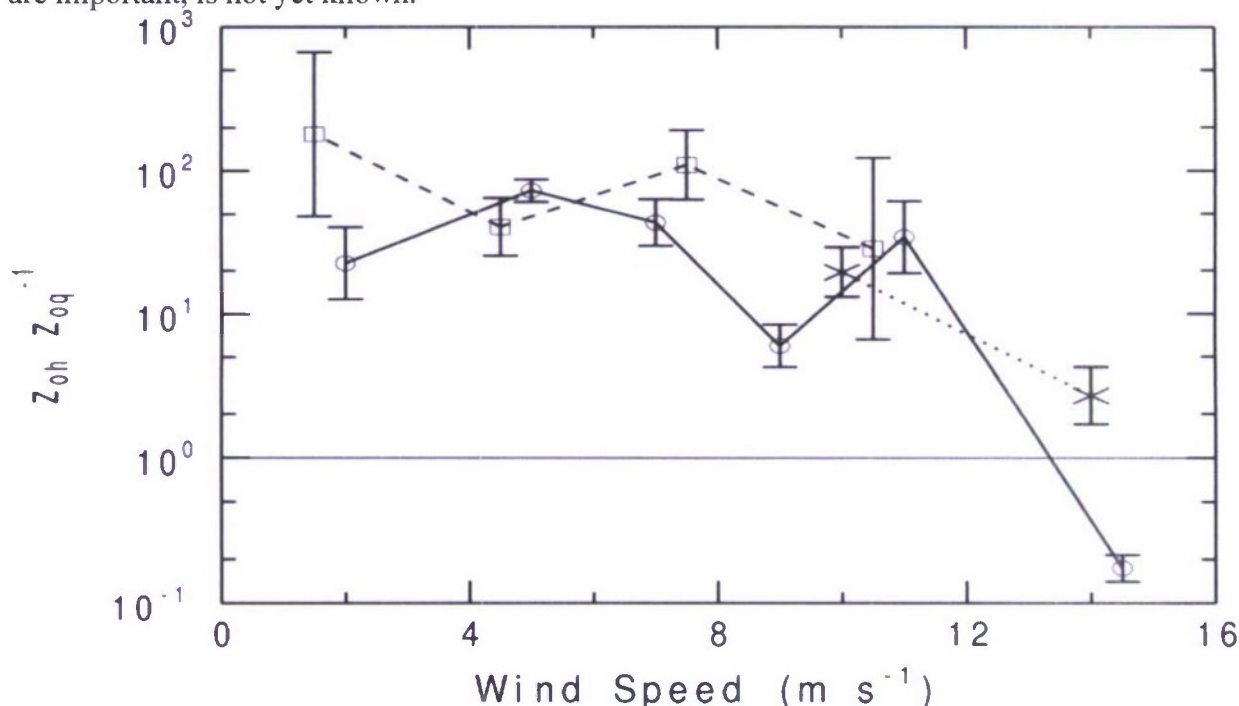

Figure 1. Observed scalar roughness length ratio (z_{oh}/z_{oq}) as a function of wind speed for combined LongEZ CBLAST and SHOWEX data (solid), ASIT CBLAST tower data (dashed) and Monterey Twin Otter data (dotted).

In a new study, initial reanalysis of the bulk formula for momentum includes the recently acquired new data sets. This study begins with a new test algorithm that avoids the large self correlation of the usual Monin-Obukhov similarity theory and the Charnock formulation. The new test algorithm relates the surface transfer coefficients to the bulk Richardson number instead of z/L, where L is the Obukhov length. To avoid self correlation, the roughness length is related to the wind speed instead of the friction velocity. The new test algorithm is currently not for actual application in models, but is designed as an instructive tool to isolate the influence of wave state.

While the new test algorithm is much simpler than the COARE algorithm, and avoids self-correlation, it performs as well as the COARE algorithm for most of the datasets. This agreement is presumably due to the near-complete mutual adjustment of the surface stress and the wave state to the wind field.

However, for some datasets, the simple test algorithm fails, but the COARE algorithm succeeds. In these cases, the wave state and surface stress maintain quasi-equilibrium with each other, but are both still adjusting to the changing wind field. For a third class of data, the test and COARE algorithms both fail, sometimes due to differences in the stress and wave directions. In these cases, the surface stress and wave state fail to achieve equilibrium or they obtain an equilibrium that is not described by the Charnock formulation. These results are very preliminary and the investigation continues.

The final work on this project focused on the relationship of the heat flux to the air-sea temperature difference for strong winds. With increasing wind speed, upward heat flux extends to small stable air-sea temperature differences. This shift and apparent counter-gradient fluxes are thought to be due to micro-scale variation of the air-sea temperature difference. This shift may not be fully understood with existing observations, but a number of possibilities have been considered.

LATEST PUBLICATIONS

L. Mahrt and D. Khelif 2010: Heat fluxes over weak SST heterogeneity. *J. Geophys. Res,* 115, D11103, doi:10.1029/2009JD013161.

Vickers D and L. Mahrt 2010: Sea-surface roughness lengths in the midlatitude coastal zone. *Quart. J. Roy. Meterol. Soc.* 136, 1089–1093.